About Continual Absorption of Radiation in the Shortwave Region

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Introduction

The problem of the anomalous (excess) absorption of shortwave optical radiation in clouds is a topic of lively discussion in the context of climate models (Wiscombe 1995, Cess et al. 1995, Ramanathan et al. 1995, Kondrat'ev et al. 1996, Titov 1996, Stephens and Tsay 1990, Rosenberg 1973). There are some hypotheses for explaining the phenomenon. Rozenberg (1973) considers the presence of absorbing carbon black aerosol in the interdrop space of a cloud to be a main cause of the excess absorption. Kondrat'ev et al. (1996) presume the most probable reason for the anomalous absorption to be the effect of multiple scattering of the shortwave radiation in clouds, which is responsible for the increase of the photon free path and, therefore, for the increase of absorptance. One more explanation is the effect of the horizontal transfer in a stochastically inhomogeneous cloud (Titov 1996). Stephens and Tsay (1990) treat the excess absorption by clouds as a result of the water vapor continuum absorption.

Thus, the question on the nature of the anomalous absorption of the shortwave radiation in clouds remains open. Among the first reasons is that the separation of this absorption in the atmosphere against the background of the more pronounced effects is a very complicated problem. Special methods are necessary to minimize the influence of impeding factors.

In the current paper we estimate the magnitude of the continuum absorption of shortwave radiation in the cloudless atmosphere ("atmospheric continuum"), leaning upon the experimental data obtained by Pkhalagov et al. (1994) and Tomasi et al. (1974) and attempt to answer whether this continuum absorption may be conditioned by the line wings of the water vapor ("spectroscopic continuum").

Experiment

The presence of the water vapor continuum absorption in spectral regions free from the absorption bands (atmospheric transparency windows) is well established (see, for example, the detailed review of relevant data by Thomas and Delay [1991]).

Extensive literature is devoted to the longwave 8- to 12-µm transparency window. The major empirical features of water vapor absorption are well understood, namely, the temperature- and pressure-dependence of the absorption in the cases of both the foreign gas broadening and self-broadening. The fundamental role of the far line wings of the water vapor in the origin of the continuum absorption can currently be considered an unassailable one.

The 3- to 5-µm region is, however, less studied. The results available enable one to register the presence of the continuum absorption with confidence and to argue that its magnitude is much less than that in the 8- to 12-µm region. Only separate measurements are available in the visible and near-infrared regions. They show the existence of an absorption and its very small magnitude. Thus, Thomas and Delay (1991) cite the value of the absorption coefficient $6 \times 10^{-10}\,\mathrm{cm}^{-1}$ near 9466 cm^{-1} (within the $1-\mu m$ window of the water vapor) obtained at the partial water vapor pressure $P_{H2O} = 16.5\,\mathrm{Torr}$, the pressure of N_2 as a broadening gas $P_{N2} = 1\,\mathrm{atm}$, and the temperature T = 30°C. The absorption in the region considered is nearly two orders of magnitude less than that in the regions of 4 or 2 µm.

The continuum absorption coefficients as dependent on the partial pressure of the water vapor in the 0.44- to 3.97-µm region were obtained by the authors from the spectral measurements of the extinction of radiation at horizontal near-ground paths in the arid zone (Pkhalagov et al. 1994). The measurements were performed under very low aerosol concentrations and relative humidity. It allows one to reduce the contribution of these factors into the variations of the extinction coefficients and to separate the weak dependence of the extinction coefficients on the absolute humidity. To do that, the aerosol component and the component conditioned by the water vapor absorption were separated using the multiple linear regression procedure. The two-parametric regression equation has the form (Pkhalagov and Uzhegov 1988)

$$\epsilon(\lambda) = K_0(\lambda) + K_1(\lambda)\epsilon(0.55) + K_2(\lambda)e$$

where $\epsilon(0.55)$ is the extinction coefficient in the region λ = 0.55 mm, e is the partial pressure of the water vapor, $K_0(\lambda)$, $K_1(\lambda)$ and $K_2(\lambda)$ are the spectral regression coefficients. The term $K_1(\lambda)\epsilon(0.55)$ determines the contribution of the aerosol component in the whole spectral region. The term $K_2(\lambda)e$ is the contribution of a component due to the water vapor absorption, which correlates with the e variations. In doing so, the value $K_2(\lambda)$ is the absorption coefficient. The comparison of the absorption coefficients so obtained (curve 1) and that calculated using LOWTRAN-7 (curve 2) in Figure 1 for λ=10.6 µm is indicative of the efficiency of the present method.

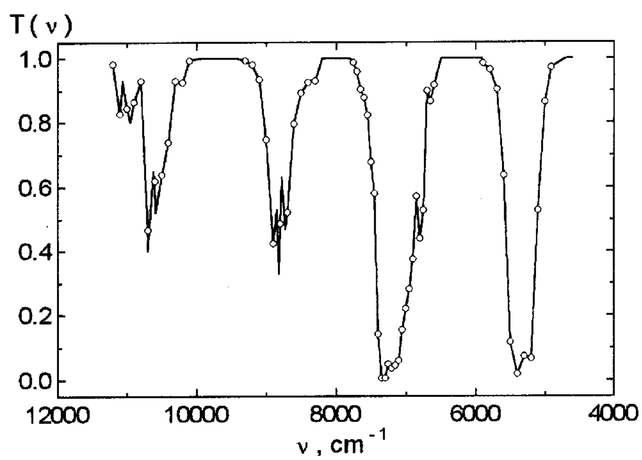

Figure 1. Extinction coefficients near the 10.6-µm wavelength vs partial pressure of water vapor. 1) contribution of the water vapor absorption obtained with present procedure; 2) the LOWTRAN-7 calculation; dots are experimental data.

Tomasi et al. (1974) have retrieved the absorption coefficients from the spectral measurements of extinction of the solar radiation in the 0.648- to 3.92-µm region. They used the data obtained under high horizontal visibility in the near-ground layer, from 25 to 50 km, to minimize the aerosol contribution in the total extinction. As in our case, the absorption coefficients by Tomasi et al. (1974) appear to be proportional to the water vapor pressure.

Separation of "Atmospheric Continuum"

The absorption coefficients obtained by Pkhalagov et al. (1994) and Tomasi et al. (1974) are used here to estimate the magnitude of the atmospheric continuum absorption in visible and near-infrared regions by removing the selective water vapor absorption. The values of the selective part of the transmission were calculated using the database by Rothman et al. (1992) and the Lorentzian line shape terminated at $\Delta\nu$ = 20 cm^{-1}. The calculation quality can be seen from comparison with experimental data (Jamanouchi and Tanaka 1985) for several absorption bands (see Figure 2).

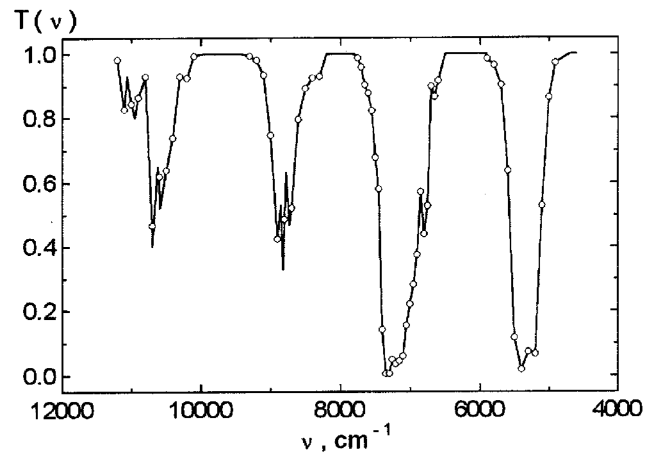

Figure 2. Transmission functions for the H_2O - N_2 mixture at total pressure P=1 atm, T=296 K and absorber amount w=0.845 g/cm^2. Curves are the experimental data (Jamanouchi and Tanaka 1985); circles are the results of present calculation with Lorentzian line shape terminated at Δv = 20 cm^{-1} from the line center.

The behavior of the atmospheric continuum absorption in the region from 0.44 up to 4.0 µm obtained from the data by Pkhalagov et al. (1994) is depicted in curve 1 of Figure 3. It shows very weak spectral dependence. (It must be emphasized that all curves in Figure 3 are drawn exclusively for the sake of visualization and are not representative of the real behavior between the dots.) The continuum absorption

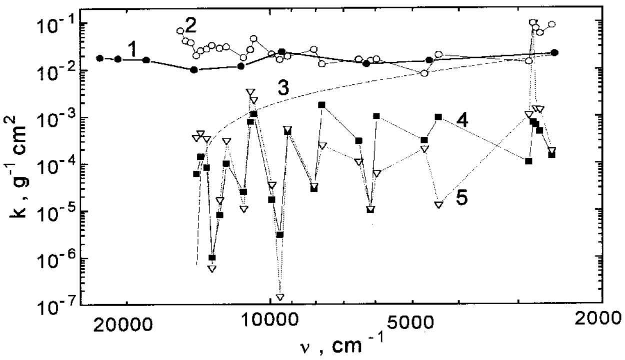

Figure 3. Absorption coefficients of the water vapor. 1) atmospheric continuum absorption from the data by Pkhalagov et al. (1994); 2) atmospheric continuum absorption from the data by Tomasi et al. (1974); 3) continuum absorption calculated after Stephens and Tsay (1990); 4) Lorentzian spectroscopic continuum calculated up to 500 cm^{-1} from the line center; 5) spectroscopic continuum absorption with the Clough contour.

coefficients similarly derived from experimental data by Tomasi et al. (1974) are given by curve 2. The curves are in agreement in the near-infrared region, and curve 2 is somewhat higher in the visible region. The fact that the absorption coefficients obtained at near-ground and inclined paths are similar is of interest because it points to the commonness of the absorption origin. Curve 3 in Figure 3 represents the spectral dependence of the water vapor continuum absorption coefficients according to the data (Stephens and Tsay 1990). They correlate with the data (Pkhalagov et al. 1994 and Tomasi et al. 1974) in the 2- to 4-μm region and are significantly below them in the visible region.

Estimates of "Spectroscopic Continuum"

Let us consider a possible explanation of the continuum absorption as associated with the far line wings of the water vapor. It is well known that the contour of the vibration-rotation lines far from their center deviates from the Lorentzian form. The near wings may be somewhat higher than Lorentzian ones and at large frequency detunings, exponential decay should develop. The detailed calculations of the line contour of the water vapor for the bands in the visible and near-infrared spectral regions are rather cumbersome. Therefore, it is meaningful to make some preliminary estimates.

Absorption coefficients by Pkhalagov et al. (1994) and Tomasi et al. (1974) are proportional to the water vapor pressure. Therefore, it is sufficient to consider the N_2-broadening case.

We calculated the absorption coefficient of the water vapor broadened by N_2 with Lorentzian line shape k_{LOR} terminated at $\Delta\nu$ ~ 500 cm^{-1}. Since the deviations of the line contour from the Lorentzian one in the direction of the exponential decay are found at frequency detunings of less than 500 cm^{-1} (see, for example, Clough 1989 [Figure 4] and Ma and Tipping. 1992 [Figure 10]), the values obtained can be considered as an upper boundary of the absorption coefficient. The values k_{Lor} given in Figure 3 (curve 4) evidently testify that the calculation even with the Lorentzian wings results in absorption coefficients significantly smaller than the experimental ones obtained from data by Pkhalagov et al. (1994) and Tomasi et al. (1974) and those calculated according to the formula by Stephens and Tsay (1990). So does the calculation with the Clough line shape (Clough 1989). Hence, the absorption by the far line wings of the water vapor in the visible and near-infrared spectral regions is too small to explain the absorption observed here. Of course, some refinements of the numbers should necessarily appear in calculations with the more accurate line shape, also taking into account the specific features of the shortwave spectral region. However, this will hardly affect the general conclusion in a decisive manner.

Conclusion

The presence of the extinction of the shortwave radiation in the cloudless atmosphere linear dependent on the absolute humidity is supported by current experiments. The selective absorption of the water vapor is calculated in the region under study and is removed from the experimental absorption, thereby leading to the atmospheric continuum. The possible contribution of the spectral line wings of the water vapor (spectroscopic continuum) into absorption in this spectral region is estimated using the Lorentzian and Clough line shapes. The magnitude of the spectroscopic continuum is insufficient to describe the measured absorption in the cloudless atmosphere. The atmospheric continuum absorption in the cloudless atmosphere by its value may, in principle, contribute to the anomalous absorption of optical radiation in clouds. However, the nature of this atmospheric continuum absorption and its behavior in clouds should be clarified.

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